

PB-217 854

NATIONAL WATER QUALITY NETWORK APPLICATIONS AND DEVELOPMENT REPORT NO. 7. A PRELIMINARY REPORT ON THE EFFECT OF PUMP AND PIPE SYSTEMS ON DISSOLVED OXYGEN CONCENTRATION

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Public Health Service
Washington, D. C.

January 1963

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**NATIONAL WATER QUALITY NETWORK
APPLICATIONS AND DEVELOPMENT REPORT**

#7

**A Preliminary Report on the
Effect of Pump and Pipe Systems on
Dissolved Oxygen Concentration**

John D. Weeks

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January 1963

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RECOMMENDATIONS

The following recommendations for future pump and pipe system designs are being made on the strength of the material developed within this report:

1. Design all intake lines so that a Reynolds number of 5000 or more is obtained at the lowest operating temperature.
2. All sample carrying lines should be insulated against temperature changes even if buried underground.
3. Submersible pumps should be utilized wherever possible until the jet pump system has been completely evaluated.

SUMMARY

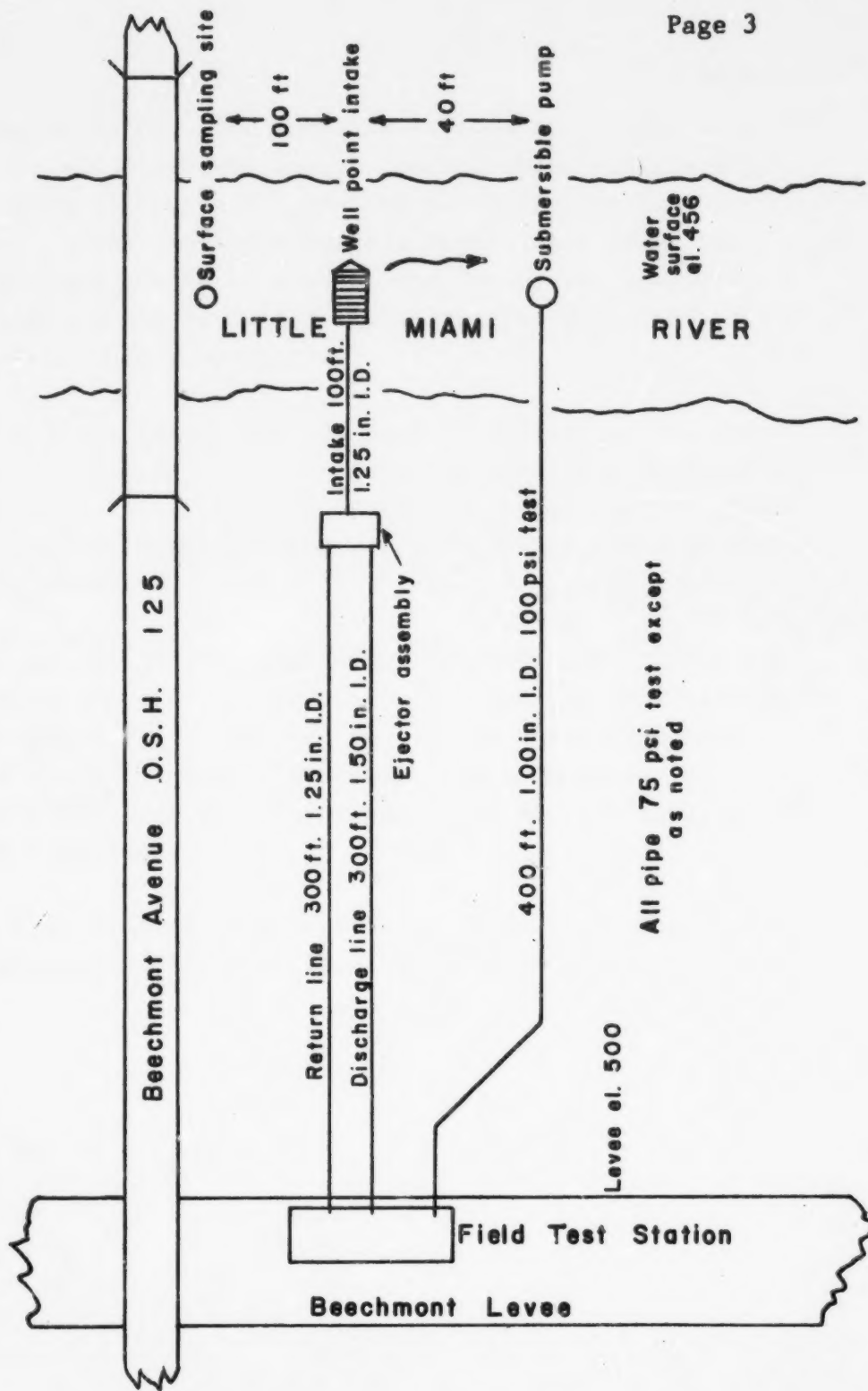
→ This report presents data which indicate that pipe and pump systems can alter the dissolved oxygen concentration, percent saturation and temperature of a water sample as it is pumped from a river to a distant sampling site. These data were obtained at the Little Miami River Field Test Station during the period July 27 to September 21, 1962. A jet and a submersible pump were delivering water through 400 feet of plastic pipe against a lift of 44 feet. A schematic diagram of the Little Miami River Field Test Station is shown in Figure 1.

The submersible pump was capable of delivering water with an average deviation of 1.4 percent saturation as compared to the river. However, it is believed that the close agreement of manifold percent saturation with the river percent saturation is coincidental and not an attribute of this particular pump system. The dissolved oxygen concentration of the manifold sample averaged 0.45 milligrams per liter less than the river's dissolved oxygen concentration. The temperature of the pumped sample was in average 1.3°C higher than the river. In this case the sample line was lying on the ground surface.

The jet pumping system delivered a sample to the test station in which the dissolved oxygen concentration was in average 2.59 milligrams per liter below the river's dissolved oxygen concentration. The percent saturation of the sample, deviated an average of 24% from the percent saturation of the river. A mean temperature increase of 1.3°C was observed on this system which had

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Figure 1. Schematic Diagram of Little Miami River Field Test Station



buried lines. The large deviations of percent saturation and dissolved oxygen concentration correlate to losses of oxygen in the line to sludge deposits formed by a slowly moving water solution. Once, when the line was purged of sludge, the jet system produced a sample whose deviation approached the deviation of the submersible pump samples.

The inability of the jet pump to deliver as satisfactory a sample as the submersible pump is a function of the very slow velocity in the jet intake line. Operation at a higher intake velocity should yield satisfactory results.

A proposal for further study has been made. This proposed experiment would attempt to relate the dissolved oxygen deficiencies to the pipe size and flow rate. It is anticipated that an optimum combination of pipe size and flow rate for minimum oxygen deficiency could be specified.

A test program to determine the best type of thermal insulation for pipe lines should also be set up.

INTRODUCTION

Most of the water quality parameters measured by the first generation of instruments required that the transducer be brought to the water. With the increasing complexity of the second generation instruments, it is becoming more desirable to bring the water to the instrument. There are many advantages in this second technique but also a major disadvantage in that little is known of the changes in a solution as it is pumped through a pipeline. Low pressure areas can reduce, and high pressure areas can increase the solubilities of gaseous compounds and cause changes in the concentration and composition of the solution. Entrained gases, if present, could be injected into the water solution to produce a synthetic sample. Low points in the pipe can harbor silt or other material which can act upon the solution. Lastly, the pipe system, by its physical size and flow rate, acts as a reservoir and can integrate sharp fluctuations of a given parameter into a smooth curve which complicates the timing of specific events.

The purpose of this study is to introduce data to show the effect of various pipe and pump systems upon the concentration of dissolved oxygen.

This test, covering the period from July 27, 1962, to September 21, 1962, was performed at the little Miami River Field Test Station.

Samples were collected from the river and at the pump manifolds. Some data were accumulated with only one pump in operation, but the majority was collected with both pumps operating. The pumps were kept running con-



Figure 2

Photograph of Little Miami River
Field Test Station showing location
of station with respect to river.

tinuously in order to develop equilibrium conditions. The frequency of sampling varied from once per day to a maximum of four times per day.

The river sample was collected off of a bridge from the center of the stream. This sample was then brought into the test station where the manifolds were sampled. It is felt that this sequence of sampling introduced a certain measure of correction for the flow time from sampling point to pump intake and from pump intake to manifold.

The Winkler method with the alkaline azide modification was used in the determination of the dissolved oxygen concentration. Percent saturations were computed.

DESCRIPTION OF PUMP AND PIPE SYSTEMS

The field test station is located on the West bank of the Little Miami River in Cincinnati, Ohio. Beechmont Avenue, Ohio State Highway 125, passes within 100 feet of the station. The elevation of the top of the levee is 500 feet above mean sea level and the normal water surface elevation was 456 feet for a lift of 44 feet.

A centrifugal pump is mounted in the station. This pump provides a high velocity stream through 300 feet of 1.25-inch diameter return line to an ejector assembly. This assembly is mounted in a manhole which is 100 feet from the wellpoint. The intake line is 1.25 inches in diameter and the discharge line is 1.50 inches in diameter. This jet pump system was providing water to the manifold at a pressure of 50 psi and at a flow rate of 3 liters per minute. With this discharge rate, the mean velocity in the intake line was 0.207 feet per second. The transit time from intake to ejector is 483 seconds. At 70°F, the intake line would have a Reynolds number of 2040. This value lies within the transition zone and most probably the flow is laminar. Since the return flow is unknown, it is impossible to describe the conditions in the discharge and return lines.

The submersible pump was installed in the river and connected to the station through 400 feet of 1.00-inch diameter line. This pump was delivering five gallons per minute to a manifold at 50 psi. Under these conditions, the mean velocity in the pipe was 2.05 feet per second and at 70°F, a Reynolds number of 16,100 would result. This is turbulent flow. Transit time from river to station is 196 seconds.

RESULTS

There were physical and hydraulic differences between the two pump systems. The submersible pump pipe line was laid on the ground surface where it was subject to solar radiation and ambient air temperature. A near constant flow rate was maintained by use of a bypass at the manifold. In contrast, the jet pump pipe line was buried and the flow rate was quite small, being about three liters per minute or 0.793 gallons per minute. This flow rate was being pulled through a 1.25-inch pipe from intake to ejector. The intake to ejector length is 100 feet and the pipe had several sags.

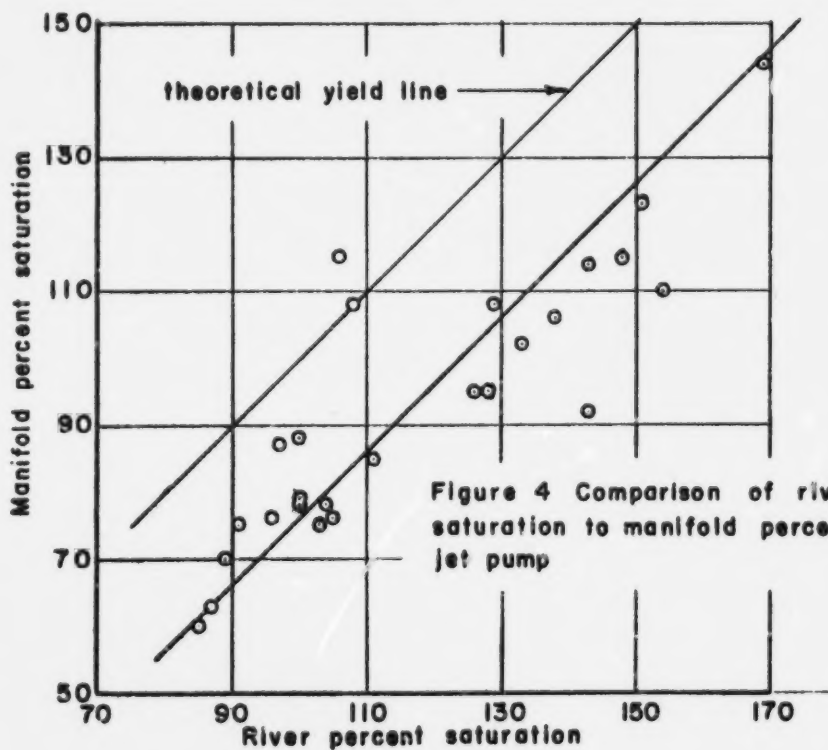
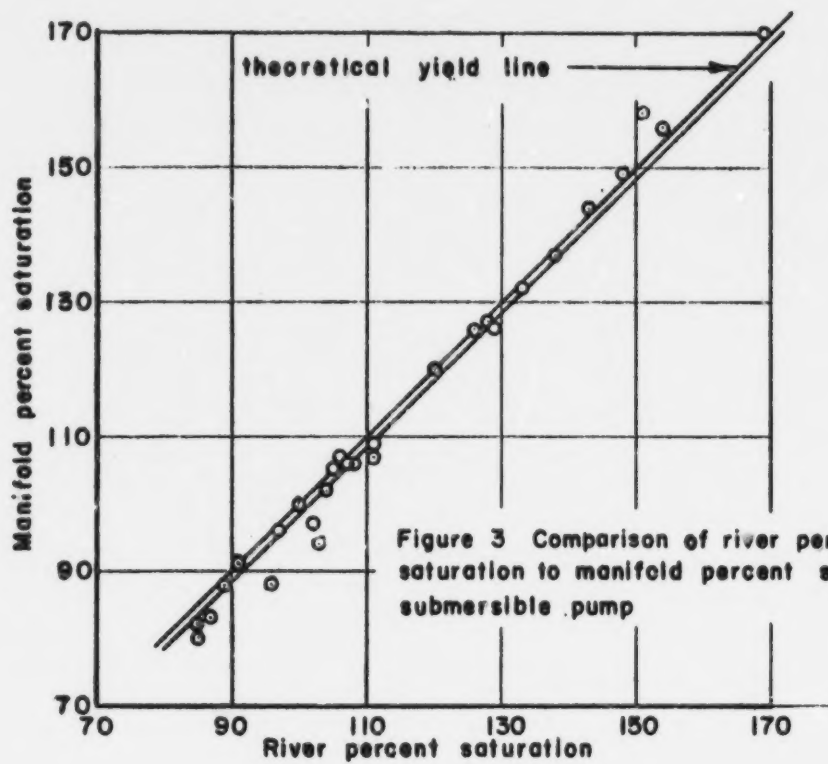
Percent Saturation: The dissolved oxygen concentrations, temperatures and computed percent saturations are tabulated in Table 1 in their order of occurrence. Figure 3 is a comparison of the river percent saturation to the submersible pump manifold percent saturation and Figure 4 is a plot of the river percent saturation against the jet pump manifold percent saturation.

The regression lines on all graphs in this report were fitted by displacing the regression line from the theoretical yield line by an amount equal to the algebraic deviation. This constrains the slope of the regression line to the slope of the theoretical yield line. More refined line fitting methods could be used, but were not utilized because of the time required. These graphs are illustrations of an effect and no attempt is being made, at this time, to ascertain basic underlying laws.

Table 1

Summary of concentrations, temperatures, and percent saturation for river, submersible and jet pump manifolds

Date	River			Submersible Manifold			Jet Manifold		
	D.O. mg/l	Temp. °C	Percent Saturation	D.O. mg/l	Temp. °C	Percent Saturation	D.O. mg/l	Temp. °C	Percent Saturation
7/27	9.3	23.0	107	8.9	24.7	106	-	-	-
8/14	7.5	22.0	85	7.0	22.2	80	-	-	-
8/15	10.2	24.0	120	10.0	25.3	120	-	-	-
8/16	8.8	23.6	102	8.4	25.3	97	-	-	-
8/17	9.5	23.7	111	9.1	25.2	109	-	-	-
8/27	12.4	27.0	143	-	-	-	9.5	25.4	114
8/28	8.5	24.0	100	-	-	-	6.7	24.9	79
8/28	11.0	24.0	129	10.5	25.2	126	9.0	25.2	108
8/29	12.0	26.8	148	11.6	29.0	149	9.3	26.2	115
8/29	12.6	27.0	151	12.3	29.0	158	10.0	26.8	123
8/29	13.6	27.0	169	13.3	28.7	170	11.6	27.0	114
8/30	9.3	25.0	111	8.8	26.0	107	7.2	25.4	85
8/30	10.4	25.8	126	10.0	28.0	126	7.8	26.0	95
8/30	10.9	26.0	133	10.5	27.8	132	8.4	26.1	102
8/30	12.4	27.0	154	12.1	29.2	156	8.9	27.0	110
8/31	8.0	25.0	96	7.4	25.0	88	6.3	25.8	76
8/31	8.6	25.3	103	7.8	25.3	94	6.2	26.0	75
8/31	8.3	-	-	6.3	-	-	1.4	26.0	17
8/31	9.2	-	-	8.0	-	-	5.1	26.2	62
9/17	7.5	22.5	85	7.2	22.4	82	5.1	23.8	60
9/17	9.1	22.5	104	8.7	24.0	102	6.6	24.1	78
9/17	12.2	24.0	143	12.0	25.2	144	7.8	24.6	92
9/18	8.0	20.0	87	7.5	20.8	83	5.5	22.7	63
9/18	11.3	21.8	128	10.9	23.8	127	8.2	23.4	95
9/18	12.2	22.1	138	11.7	23.8	137	9.1	23.8	106
9/19	9.2	19.2	100	9.0	-	-	6.9	22.0	78
9/19	9.7	19.5	105	9.5	20.6	105	6.7	22.0	76
9/20	8.6	17.5	89	8.3	18.5	88	6.3	20.8	70
9/20	9.5	18.1	100	9.3	19.5	100	7.9	21.0	88
9/20	10.8	19.0	106	10.7	20.0	107	10.3	21.0	115
9/20	11.0	19.0	108	10.7	19.8	106	9.7	21.0	108
9/21	9.1	16.0	91	8.9	17.0	91	6.9	20.0	75
9/21	9.5	16.5	97	9.2	18.0	96	8.0	20.0	87



Inspection of Figure 3 and Table 2 shows a fairly close agreement between the river percent saturation and the percent saturation of the water delivered by the submersible pump. The algebraic deviation was 1.4% and the absolute deviation was 2.4% with deviations ranging from -7% to +9%. From the close agreement between the river and manifold values, it is concluded that the percent saturation of the water is remaining essentially constant in this pipe and pump system.

Inspection of Figure 4 shows that the jet pump is delivering water into the field station whose percent saturation is usually well below the river value. In Table 2, are tabulated the differences between the river values and the appropriate manifold values. From Table 2, it can be seen that the jet pump manifold percent saturation averages 24 percent below the river. One value was observed which agreed with the river and one value exceeded the river.

Dissolved Oxygen: The relationship between the river's dissolved oxygen concentration and the submersible pump manifold oxygen concentration is presented graphically in Figure 5. From Table 2, it can be seen that the best agreement was 0.1 mg/l and the greatest deviation was 2.0 mg/l. The overall average deviation was 0.45 mg/l. Figure 6 presents the relationship between the river's dissolved oxygen concentration and the dissolved oxygen content of the water delivered into the station by the jet pump. From Table 2, a mean deviation of +2.59 mg/l has been computed. No value agrees any closer than 0.5 mg/l with the river value and the maximum observed deviation is 6.9 mg/l.

Table 2

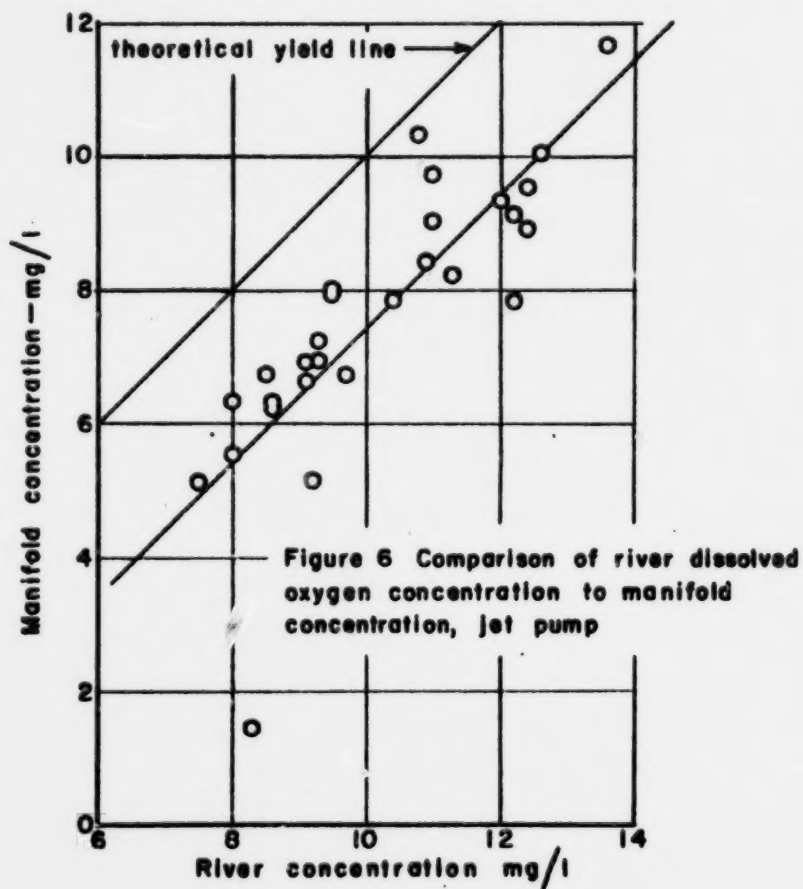
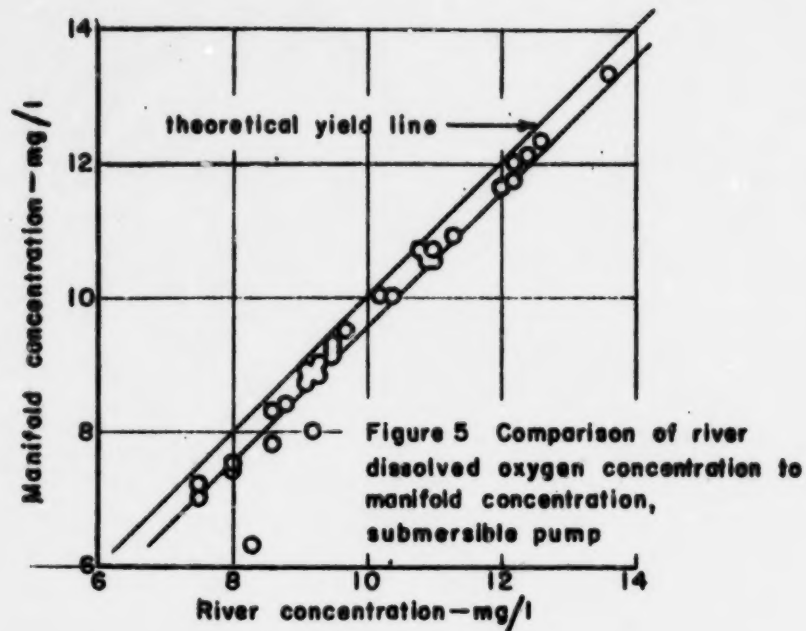
Deviations of jet pump and submersible pump manifold percent saturation, dissolved oxygen concentration and temperature from corresponding river parameters

Date 1962	Submersible Pump Manifold			Jet Pump Manifold		
	D.O. Deviation mg/l	Temperature Deviation °C	Percent Saturation Deviation	D.O. Deviation mg/l	Temperature Deviation °C	Percent Saturation Deviation
7/27	+ 0.4	- 1.7	+ 1	-	-	-
8/14	+ 0.5	- 0.2	+ 5	-	-	-
8/15	+ 0.2	- 1.3	0	-	-	-
8/16	+ 0.4	- 1.7	+ 5	-	-	-
8/17	+ 0.4	- 1.5	+ 2	-	-	-
8/27	-	-	-	+ 2.9	+ 1.6	+ 29
8/28	-	-	-	+ 1.8	- 0.9	+ 21
8/28	+ 0.5	- 1.2	+ 3	+ 2.0	- 1.2	+ 21
8/29	+ 0.4	- 2.2	- 1	+ 2.7	+ 0.6	+ 33
8/29	+ 0.3	- 2.0	- 7	+ 2.6	+ 0.2	+ 28
8/29	+ 0.3	- 1.7	- 1	+ 2.0	0	+ 25
8/30	+ 0.5	- 1.0	+ 4	+ 2.1	- 0.4	+ 26
8/30	+ 0.4	- 2.2	0	+ 2.6	- 0.2	+ 31
8/30	+ 0.4	- 1.8	+ 1	+ 2.5	- 0.1	+ 31
8/30	+ 0.3	- 2.2	- 2	+ 3.5	0	+ 44
8/31	+ 0.6	0	+ 8	+ 1.7	- 0.8	+ 20
8/31	+ 0.8	0	+ 9	+ 2.4	- 0.7	+ 28
8/31	+ 2.0	-	-	+ 6.9	-	-
8/31	+ 1.2	-	-	+ 4.1	-	-
9/17	+ 0.3	- 0.4	+ 3	+ 2.4	- 1.8	+ 25
9/17	+ 0.4	- 1.5	+ 2	+ 2.5	- 1.6	+ 26
9/17	+ 0.2	- 1.2	- 1	+ 4.4	- 0.6	+ 51
9/18	+ 0.5	- 0.8	+ 4	+ 2.5	- 2.7	+ 24
9/18	+ 0.4	- 2.0	+ 1	+ 3.1	- 1.6	+ 33
9/18	+ 0.5	- 1.7	+ 1	+ 3.1	- 1.7	+ 32
9/19	+ 0.3	-	-	+ 2.4	- 2.8	+ 22

Table 2, Cont'd.

Deviations of jet pump and submersible pump manifold percent saturation, dissolved oxygen concentration and temperature from corresponding river parameters

Date 1962	Submersible Pump Manifold			Jet Pump Manifold		
	D.C. Deviation mg/l	Temperature Deviation °C	Percent Saturation Deviation	D.C. Deviation mg/l	Temperature Deviation °C	Percent Saturation Deviation
9/19	+ 0.2	- 1.1	0	+ 3.0	- 2.5	+ 29
9/20	+ 0.3	- 1.0	+ 1	+ 2.3	- 3.3	+ 19
9/20	+ 0.2	- 1.4	0	+ 1.6	- 2.9	+ 12
9/20	+ 0.1	- 1.0	- 1	+ 0.5	- 2.0	- 9
9/20	+ 0.3	- 0.8	+ 2	+ 1.3	- 2.0	0
9/21	+ 0.2	- 1.0	0	+ 2.2	- 4.0	+ 16
9/21	+ 0.3	- 1.5	+ 1	+ 1.5	- 3.5	+ 10
N	31	28	28	28	26	26
$\sum d$	+13.8	-36.1	+40	+72.6	-34.9	+627
$\sum d $	13.8	36.1	66	72.6	39.7	645
d mean	+ 0.45	- 1.3	+ 1.4	+ 2.59	- 1.3	+ 24
d mean	+ 0.45	1.3	2.4	+ 2.59	1.5	25



Temperature: Both systems showed the same algebraic mean deviation of -1.3°C . It is felt that two compensating factors are at work in this particular evaluation. During the early part of this study, the submersible pump data are strongly affected by air temperatures which were higher than the river temperature. As the weather cooled, the air temperature approached the water temperature and the variability was lessened. Conversely, for the jet pump, it appears that during the warmer portion of the study the earth temperatures were near the water temperatures and with the onset of cooler weather the earth temperature lagged the water temperature and gave rise to a warmer sample.

For this reason, all pipe installations should be insulated in order to reduce heat transfer into or out of the sample. Temperature changes would still be present but the rate of change would be less and the delivered sample would more nearly indicate the temperature of the source.

DISCUSSION OF RESULTS

The submersible pump delivered water which nearly reproduced the percent saturation in the river. It is believed that a propitious combination of circumstances were in existence on the submersible pump system. Paradoxically, the percent saturation is remaining almost constant with a decrease in dissolved oxygen and an increase in temperature. In the range of observed temperatures and concentrations, the dissolved oxygen reduction is being offset by the reduction in the saturation concentration. With an estimated error of ± 0.05 mg/l in the dissolved oxygen determination, sufficient overlap is then provided so that apparently equal percent saturations are obtained, where in fact, two different waters, having near equal percent saturations are being sampled.

The four largest concentration deviations all occurred on one day and require explanation. On August 31, 1962, rain had been falling all morning and by afternoon the Little Miami River was rising. The Little Miami River is heavily polluted with organic materials. The flood wave in moving downstream stirred up oxygen-consuming or oxygen deficient materials which clogged the pump screen. A large deficiency occurred in the jet system on the same day also.

On September 20, 1962, the jet pump system suddenly started discharging mud. A turbidity of 1500-1800 Jackson candle units was sustained for two hours. During this interval, the turbidity of the submersible discharge was 105 Jcu. Inspection of the river showed no unusual conditions. Following this flushout, the

jet pump system deviation reached its best value of 0.5 mg/l. The performance of the jet system at this time approached the submersible pump system which had a deviation of 0.1 mg/l.

From the data obtained, it appears that both pump systems are capable of delivering satisfactory samples if the intake system are clean. Both systems had concentration deficits indicating the presence of oxygen-consuming matter. These deficits are not chargeable to the mechanics of the pumping process because they varied in magnitude and frequency. If oxygen is being released by cavitation in the high-velocity areas of the pump, the gas is then redissolving on the high pressure discharge side of the pump.

The jet pump intake system was shown to have a very low Reynolds number at 70°F. At lower temperatures, this value would decrease and the flow regimen would be even more quiescent.

The submersible pump pipeline operates within the turbulent flow region. However, dissolved oxygen deficiencies did occur and suggest that either higher degrees of turbulence are necessary or else there is a value beyond which the dissolved oxygen deficiency cannot be decreased.

The exact mechanism causing a deficit was not ascertained. It has been tacitly assumed that sludge deposits were harboring some oxygen-consuming material or mechanism. The exact cause will not require determination at this time, provided that a flow condition can be established where such deficits will not occur.

RECOMMENDATIONS FOR FURTHER STUDY

The question remaining to be solved is concerned with pipeline design. At what flow rates and turbulence conditions can a reduction in dissolved oxygen be anticipated? What is the optimum pipe size for a given flow? What are the effects of sags and other areas where sludge depositions can occur? What is the frequency of self-cleaning? These questions have a direct bearing upon the engineering design of an intake system.

The following experiment is proposed: Obtain several sizes of pipe and several flow regulators. Record the dissolved oxygen (mg/l or percent saturation) and temperature of the influent and effluent. Develop a method of measuring the dissolved oxygen deficiency. For example, milligrams per liter deficiency, or percent saturation deficit. Relate these deficiency values to the Reynolds number. A plot similar to the Moody Diagram is anticipated. It is felt that such a plot would define the lowest operating Reynolds number which would in turn set the flow rate-diameter ratio. By continuous recording, it is expected that the flush-out frequency could be determined by those occasions when the influent and effluent were in very close agreement. The use of flexible tubing would allow a sag of given dimensions to be duplicated.

This experiment would be performed at the field test station because of the availability of organically-polluted water. The results would be limited to similar waters but would provide a first step in the design

of an intake. Subsequent intakes could be evaluated in a similar manner to broaden the scope of the design criteria.

The insulation test would also be performed at the field test station because of space requirements. This test will require continuous recording of inlet and outlet water temperatures and air temperatures.

The amount of heat added to the sample would have to be related to the flow rate and the temperature of the medium surrounding the pipe. Provision must be made for simulating in-air and underground locations. A standard pipe size and flow rate could be adopted when evaluating different kinds and amounts of insulating materials.

A second phase of the insulation test would include a study of the effect of adding heat to a water sample. This would pertain to those sites where freezing is a possibility. Is there an optimum temperature of the delivered water where the dissolved oxygen concentration and/or percent saturation are not adversely affected? If such a temperature exists, then heater control devices must be installed in the sample discharge line and set to control from freezing to the no-effect temperature.